

THE PERFORMANCE OF TIG WELDED SIMILAR AND DISSIMILAR WELDMENTS UNDER TENSILE LOADING: AN EXPERIMENTAL INVESTIGATION

SEWA SINGH¹, VIKAS CHAWLA² & GURBHINDERSINGH BRAR³

¹Research Scholar, IKG-Punjab Technical University, Kapurthala, Punjab, India

²Professor, IKG-Punjab Technical University, Kapurthala, Punjab, India

³Professor, Guru Kashi University, Talwandi Sabo, Punjab, India

ABSTRACT

Fusion welding is a widely used technique to prepare intermetallic joints of similar and dissimilar metals. Tungsten Inert Gas (TIG) welding is a popular fusion welding technique. Mechanical properties of a weldment are supposed to be an indicator of weldment quality, in present research the tensile strength of similar and dissimilar weldment of ASME SA 213 GR. T11 and BS 3059:1987 PT 1 ERW 320 welded with TIG welding has been investigated. The results revealed that maximum tensile strength of dissimilar joint has been observed when welding current and gas flow rate was 110A and 10 Litre/min respectively and the specimen was preheated at 200° C. The experimental results have been statistically tested by using two way ANOVA and Multiple Regression Analysis. The mathematical predictive model has been discussed based on regression analysis.

KEYWORDS: Dissimilar Welded Joints, Tensile Strength, TIG Welding, ANOVA & Multiple Regression

Received: May 18, 2019; **Accepted:** Jun 20, 2019; **Published:** Jul 15, 2019; **Paper Id.:** IJMPERDAUG2019104

INTRODUCTION

The oldest technique to join metals is undoubtedly fusion welding and its role in fabrication industry, piping joints in refineries, ship building, aerospace application, nuclear power plant fabrication and repair etc. is very important. Being a versatile process, welding technique facilitates joining of almost all metals, however the selection of appropriate technique to produce maximum penetration in the metals to be welded yields good quality weld. Manual Arc Welding (MA), Metal Inert Gas (MIG) Welding and Tungsten Inert Gas (TIG) Welding techniques are among the most commonly used welding techniques [1]. TIG welding is however the most popular technique as it is capable of welding a wide variety of metals [2, 3] and almost in all positions of welding [4]. TIG welding finds its applications in aerospace, automobile, marine, fabrication sector industries [5].

LITERATURE REVIEW

A variety of researches have been carried out on TIG welding techniques from different aspects, some of them are discussed hereafter wherein the researchers have explored the effects of different process parameters of TIG welding on the weld quality. It is supposed that a correctly produced TIG welding joint possesses comparatively high quality than those produced by the other techniques especially in case of Stainless Steel, Aluminum, Magnesium and Copper alloys [6] and [7]. Welding current welding speed, size of tungsten electrode, Size/type of filler wire, gas flow rate etc. are some process parameters influencing the quality of joint [8]. It has

also been reported that a low welding speed yields more tensile strength [9]. The optimum values of welding current and welding speed during the TIG welding of low carbon steel and Aluminium AA1050 was reported to be 135A and 3.2 mm/s respectively and maximum tensile strength with the said combination was 61.37MPa[10]. Activated TIG (A-TIG) welding is reported to increase the depth of penetration and lower the weldment distortion, welding current, welding speed reported to have direct influence on output parameters [11] and [12] type of current i. e. whether the current used for ATIG is AC or DC also affects the mechanical properties of the weldment[13]. The optimum range of welding current, voltage and welding speed for the TIG welding of Incoloy 800HT was found to be 110 A, 12 V and 1.5 mm/s respectively [14]. Fusion welding are often associated with residual stresses due to extents of heat affected zones, post welding heat treatment is supposed to relieve such stresses thereby improving weld quality and life. Post welding heat treatment at 700°C for one hour has reportedly improved the tensile strength of aerospace engine components by 2.1% [15]. Considerable decline in toughness of TIG welded metals has been observed with post welding heat treatment [16]. Heat input is another important influencing factor affecting microstructure of the weldment, the volume fraction of austenite increases with increase in heat input [17]. In spite of being fusion welding TIG welded joints possess comparable fatigue strength with that produced by solid state welding techniques, reportedly the fatigue strength of Aluminium alloy 6061-T6 welded with TIG welding was observed to be almost similar to that welded by friction stir welding[18]. Failure mode evolution investigation has revealed that critical strain for void nucleation is smaller and growth rate of void is higher in TIG welded joints [19]. The life of a weldment is influenced by the environmental factors of its work envelop, the components employed in nuclear power plants are subjected to thermal aging and the reported thermalaging time of TIG welded components employed in offshore nuclear power plants directly influenced the yield strength of the weldment [20]. TIG welding technique is good enough to be used for weld braze joints of aluminium alloy and galvanised steel [21].

Above stated literature survey has revealed that lots of research work is being done to explore numerous aspects of TIG welding. It has also been observed that mechanical properties (tensile strength in most of the cases) of the weldment are considered to be the prime indicator of the quality of sound weldment. Very few researches have been observed on application of TIG welding on boiler steel materials and specifically the materials in current study have not been explored by fellow researchers. So here in an attempt has been made to explore tensile strength of similar and dissimilar TIG welded specimens of boiler tube steel.



Figure 1: Welded Boiler Tubes

MATERIALS AND METHODOLOGY

A Variety of boiler tubes are being used in the boiler fabrication industry such as T11, T22, T99 etc.; ASME SA 213 GR. T11 (hereafter also referred to as A) and BS 3059:1987 PT 1 ERW 320 (hereafter also referred to as B) tubes find their application in boiler fabrication units based in Jalandhar (Punjab). So these two material types were used in the present study.

Figure1 shows the welded boiler tubes and Table 1 shows the chemical composition of the tube materials used in the present study. Filler wire of BS 3059:1987 PT 1 ERW 320 was used.

Table 1: Chemical Composition %

Element	BS 3059:1987 PT 1 ERW 320		ASME SA 213 GR. T11	
	Manufacturer's Cert	Observed	Manufacturer's Cert	Observed
C	0.12	0.371	0.12	0.12
Si	0.21	0.469	0.68	0.646
Mn	0.59	1.01	0.48	0.511
P	0.018	0.0367	0.01	0.007
S	0.004	0.043	0.01	0.0031
Cr			1.17	1.11
Mo			0.47	0.469
Ni			0.04	0.0527
V			0.01	0.0021
Al			0.01	-----
Cu			0.09	-----

Industry practice revealed that for most of the boiler tube materials the workpiece is required to be pre heated at 150° to 200° before making weld joint. So in the present study, three different experimental conditions were decided to be investigated viz. Welding at Room Temperature (RT), Preheated at 150° (PH150) and Preheated at 200° (PH200) referred to as levels in Table 2 below; welding current and gas flow rate were the two variable process parameters.

Manual method of welding was used; the two process parameters included in the study were welding current and gas flow rate. Three set of experiments keeping gas flow rate constant and varying current in three different levels were carried out. Flow 1, 2 and 3 in Table 2 refers to gas flow rate of 8 Litre /min, 10 Litre /min and 12Litre /min respectively.

Table 2: Different Experimentation Conditions

S. No.	GAS Flow	Level		
		Level 1 (RT)	Level 2 (PH150)	Level 3 (PH200)
1.	Flow 1	90 A	90 A	90 A
2.		100 A	100 A	100 A
3.		110 A	110 A	110 A
4.		120 A	120 A	120 A
5.	Flow 2	90 A	90 A	90 A
6.		100 A	100 A	100 A
7.		110 A	110 A	110 A
8.		120 A	120	120 A
9.	Flow 3	90 A	90 A	90 A
10.		100	100 A	120 A
11.		110 A	110 A	112 A
12.		120 A	120 A	120 A

EXPERIMENTAL OBSERVATIONS

Tensile Strength of the welded specimens was tested on Universal testing Machine (UTM) of FIE make installed at Anand College of Engineering and Management, Kapurthala. Specimen from welded pipes were prepared according to ASTM standards as shown in Figure2

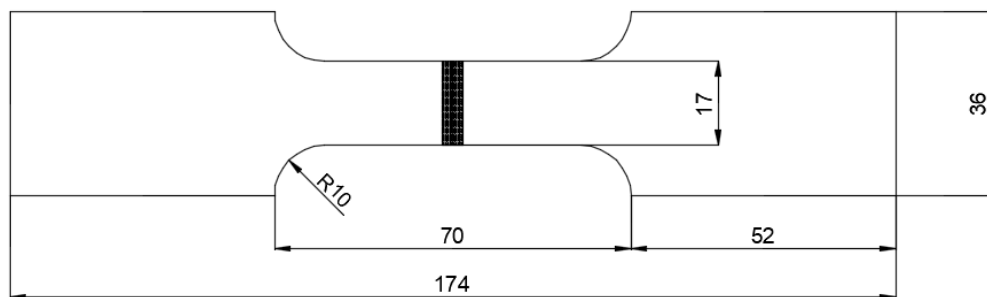


Figure 2: Tensile Test Specimen

It is apparent from Table 3 that parent material ASME SA 213 GR. T11 has much more strength under tensile loading than that of BS 3059:1987 PT1 ERW 320. However the later has elongated more than the former.

Table 3: Tensile Strength of Parent Metals

S. No.	Material	Yield Strength (in N/mm ²)	Ultimate Tensile Strength (in N/mm ²)	Elongation
1	ASME SA 213 GR. T11	192.55	615.62	24.04%
2	BS 3059:1987 PT 1 ERW 320	170.07	557.20	25.04%

The similar welded specimens (viz. A-A and B-B) were tested for their tensile strength on universal testing machine (UTM) FIE make, Model-UTE-40, maximum capacity 400kN and the observations have been recorded in Table 4. It is apparent from the table that as current increases the tensile strength increases till 110 A of current and thereafter decreases almost for all the sets of experiments however some exceptions are there, they may be due to experimental error induced due to uncontrolled environmental factors. It can also be observed from table 4 that maximum tensile strength has been yielded by the specimens welded at 110 A and having constant gas flow of 10 Litre/ min. As far as ASME SA 213 GR. T11 is concerned the maximum tensile strength of 601.63 N/mm² has been yielded by the specimens welded without any pre heating whereas BS 3059:1987 PT 1 ERW 320 has responded well by yielding tensile strength of 544.17 N/mm² when preheated at 150° before welding.

Dissimilar metal joints of the same materials have responded differently as compared to the behaviour of individual metals while welding under similar situations Table 5 depicts the tensile strength observations of dissimilar metal joints of both ASME SA 213 GR. T11 and BS 3059:1987 PT 1 ERW 320.

Table 4: Tensile Strength of TIG Welded Similar Joints (in N/mm²)

Level	Current	ASME SA 213 GR. T11			BS 3059:1987 PT 1 ERW 320		
		Flow1	Flow2	Flow3	Flow1	Flow2	Flow3
Level1	C1	416.51	513.26	506.26	401.25	450.54	453.32
	C2	439.25	542.49	559.7	410.69	486.12	481.43
	C3	479.29	601.63	597.64	426.91	510.23	506.24
	C4	510.86	578.42	577.37	445.63	507.31	506.58
Level2	C1	425.12	523.24	510.23	410.2	477.29	490.63
	C2	442.65	529.57	516.79	413.25	520.29	523.67
	C3	485.32	537.4	535.32	433.75	544.17	541.26
	C4	518.29	530.37	527.19	469.26	541.55	540.69
Level3	C1	521.23	529.38	526.8	398.26	407.72	421.87
	C2	540.6	535.3	540.38	400.53	426.35	437.13
	C3	556.38	568.18	561.14	416.22	440.45	439.84
	C4	547.12	552.71	556.28	435.52	439.21	443.57

It is clear from Table 5 that in case of dissimilar joint of the material in study the maximum strength of 563.49 N/mm² has been achieved when samples preheated at 200° has been welded at 110 A under the shielding of 10 Litre/min inert gas. It is worth mentioning here that all the samples failed on BS 3059:1987 PT 1 ERW 320 side of the weldment. Ductile fracture has been observed by visual inspection.

Table 5: Tensile Strength of TIG Welded Dissimilar Joints (in N/mm²)

Level	Current	Dissimilar Joint		
		Flow1	Flow2	Flow3
Level1	C1	412.9	416.23	418.39
	C2	427.24	419.56	429.85
	C3	441.37	459.29	446.72
	C4	449.58	452.12	460.78
Level2	C1	439.29	447.62	489.78
	C2	450.57	479.97	517.59
	C3	467.13	483.75	539.16
	C4	460.28	488.27	496.32
Level3	C1	508.41	532.82	512.72
	C2	523.46	551.26	534.38
	C3	540.68	563.49	559.27
	C4	535.28	555.29	552.3

STATISTICAL TREATMENT AND DISCUSSIONS

The Literature has suggested the use of statistical tools to validate the experimental data, here in three different levels two parameters viz. current and gas flow rate were considered so two way analysis of variance (ANOVA) was used to test the experimentally obtained data as used in literature[22], [23]. The test was applied on three set of data two sets belong to tensile strength data for ASME SA 213 GR. T11 and BS 3059:1987 PT 1 ERW 320 from table 4.

Following are three null hypotheses taken for two way ANOVA:

- H_{01} = The effect of current on tensile strength variance is not significant.
- H_{02} = The effect of Flow Rate is not significant on variance of tensile strength.
- H_{03} = The interaction between current and flow rate is insignificant.

In addition to ANOVA, multiple regression test has also been used to develop a mathematical model to predict the optimum tensile strength of the weldment using the said setting of parameters. Again ANOVA has been used to test the significance of the fit of regression model. The following sub section describes the results of ANOVA and regression analysis and their discussion.

Similar Joint of ASME SA 213 Gr. T11

The table 6 depicts the ANOVA table for ASME SA 213 Gr. T11 at level of significance of 5% i. e. $\alpha=0.05$. f-statistics for current is 5.14962 which is greater than 3.354131 the f-critical for the same and p-value 0.012749 which is smaller than that of α , hence H_{01} is rejected, in other words the current has significant impact on the variation of tensile strength of the weldments. Similarly for the contribution of flow rate the f-statistics comes out to be 13.89688 which is greater than 3.544131 and p-value is 0.0000709 which is again smaller than α , so H_{02} is also rejected i. e. flow rate of gas has significant impact on tensile strength of welded specimen. F-statistics for interaction between variables is 3.519517 being larger than f-critical 2.727765 at p-value 0.019495 which in turn smaller than α . Hence H_{03} also cannot be accepted.

That is both the variables are significantly associated.

Table 6: ANOVA Statistics for ASME SA 213 GR. T11 Weldments

Source of Variation	SS	df	MS	F	P-value	F crit
Current	8599.724	2	4299.862	5.149612	0.012749	3.354131
Flow Rate	23207.44	2	11603.72	13.89688	7.09E-05	3.354131
Interaction	11755.01	4	2938.753	3.519517	0.019495	2.727765
Within	22544.66	27	834.9875			
Total	66106.84	35				

Table 7 shows the model summary of regression analysis, multiple correlation coefficient 'R' can be regarded as one measure of quality of dependent variable which is ultimate tensile strength (UTS) in present case. 0.651 as a value of 'R' reflects good level of prediction. The Value of the coefficient of determination ('R²') represents the proportion of variance of UTS that can be explained by the process parameters of the present study. In simple words it can be said that the independent variables in current study address the 42.4% variation of the UTS.

Table 7: Model Summary of Regression Analysis Similar Weldment (ASME SA 213 Gr. T11)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.651 ^a	.424	.370	34.50874
^a Predictors: (Constant), Current, Flow Rate, Temperature				

ANOVA table below (table 8) depicts whether the overall regression model represents good fit for the data or otherwise; using F-statistics. It is clear that with F (3,32)=7.853, p<0.005 it can be safely declared that the regression model is good fit of the data for the similar welding of ASME SA 213 Gr. T11.

Table 8: ANOVA Statistics of Regression Analysis for Similar Weldment (ASME SA 213 Gr. T11)

Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	28056.583	3	9352.194	7.853
	Residual	38107.311	32	1190.853	.000 ^b
	Total	66163.894	35		
^b Predictors: (Constant), Current, Flow Rate, Temperature					

The generalised equation for predicted value of tensile strength of this material can be written from the regression analysis as below:

$$UTS_{T11 \text{ pre}} = 316.18 + (1.381 \times \text{Current}) + (5.6 \times \text{Flow Rate}) + (0.51 \times \text{Temperature})$$

Similar Joint of BS 3059:1987 PT1 ERW 320

The Table 9 shows the ANOVA statistics for BS 3059:1987 PT1 ERW 320 at level of significance of 5% i. e. $\alpha=0.05$. For current f-statistics are 26.08257 which is greater than f-critical i. e. 3.354131 for the same and p-value 0.000000493 which is smaller than that of α ; hence H_{01} cannot be accepted i. e. the current has significant impact on the variation of tensile strength of the weldments. Similarly for the contribution of flow rate the f-statistics comes out to be 26.91734 which is greater than 3.544131 and p-value is 0.000000372 which is again smaller than α , so H_{02} is also rejected i. e. flow rate of gas has significant impact on tensile strength of welded specimen. Thirdly f-statistics for interaction between variables is 3.441295 being larger than f-critical 2.727765 at p-value 0.021353 which in turn smaller than α . Hence H_{03} also cannot be accepted. That is both the variables are significantly associated.

Table 9: ANOVA Statistics for BS 3059:1987 PT 1 ERW 320 Weldments

Source of Variation	SS	df	MS	F	P-value	F crit
Current	26977.44	2	13488.72	26.08257	4.93E-07	3.354131
Flow Rate	27840.86	2	13920.43	26.91734	3.72E-07	3.354131
Interaction	7118.727	4	1779.682	3.441295	0.021353	2.727765
Within	13963.18	27	517.1546			
Total	75900.2	35				

In Table 10 multiple correlation coefficient 'R' comes out to be 0.672 thereby indicating good level of prediction of UTS for this set of experiments. Likewise from the value of the coefficient of determination ('R²') it can be said that the current, flow rate of gas and temperature conditions in current case explain 45.2% variability of ultimate tensile strength.

Table 10: Model Summary of Regression Analysis Similar Weldment (BS 3059:1987 PT1 ERW 320)

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.672 ^a	.452	.401	36.23701
^a Predictors: (Constant), Current, Flow Rate, Temperature				

ANOVA table for regression analysis of BS3059:1987 PT1 ERW320 shown below (Table 11) depicts that the regression model holds good fit for this case of investigation also as F-statistics $F(3, 32) = 8.800$, $p < 0.005$ i. e. effect of independent variables is well described by the regression model associated to present case of study.

Table 11: ANOVA Statistics of Regression Analysis for Similar Weldment (BS 3059:1987 PT1 ERW320)

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	34664.891	3	11554.964	8.800	.000 ^b
	Residual	42019.866	32	1313.121		
	Total	76684.757	35			
^b Predictors: (Constant), Current, Flow Rate, Temperature						

The generalised equation for predicted value of tensile strength of BS 3059:1987 PT1 ERW 320 material can be written from the regression analysis as below:

$$UTS_{3059 \text{ pre}} = 277.538 + (1.287 \times \text{Current}) + (6.374 \times \text{Flow Rate}) - (0.147 \times \text{Temperature})$$

Dissimilar Joint

Statistics for dissimilar weldment has been shown in table 12., apparently f-statistics for current here are 99.73831 much higher than f-critical 3.354131 and p-value is also very small as compared to $\alpha = 0.05$. It reflects the importance of current in dissimilar weldments. Likewise F-statistics for flow rate is higher than f-critical and p-value is also smaller than α ; depicting the significant influence of the independent variable over the dependent one, on the same pattern interaction between variables is also significant thereby rejecting H_{01} , H_{02} and H_{03} .

Table 12: ANOVA Statistics for Dissimilar Weldments

Source of Variation	SS	df	MS	F	P-value	F crit
Current	64054.87	2	32027.44	99.73831	3.39E-13	3.354131
Flow Rate	3879.257	2	1939.629	6.040298	0.006791	3.354131
Interaction	3845.089	4	961.2723	2.993548	0.036268	2.727765
Within	8670.097	27	321.1147			
Total	80449.32	35				

Model summary for the regression model depicted in Table 13 indicates excellent level of prediction of dependent variable i. e. ultimate tensile strength, as apparently the multiple correlation coefficients 'R' for dissimilar weldment case is 0.904. Moreover as $R^2 = 0.816$, it signifies that regression model for dissimilar weldment case is able to explain the variance of output parameter by an extent of 81.6%.

Table 13: Model Summary of Regression Analysis Dissimilar Weldment

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.904 ^a	.816	.799	21.48482
^a Predictors: (Constant), Current, Flow Rate, Temperature				

Significance of Regression model is reflected from ANOVA results in Table 14 below. F-statistics for regression analysis of dissimilar weldments of ASME SA 213 Gr. T11 and BS3059:1987 PT1 ERW320, $F(3, 32) = 47.428$ and $p < 0.005$ apparently indicates that the regression model holds very good fit, in other words interaction between the process parameters and the weld quality indicator taken for the current study is well explained by the regression model.

Table 14: ANOVA Statistics of Regression Analysis for Dissimilar Weldment

	Model	Sum of Squares	df	Mean Square	F	Sig.
1	Regression	65678.202	3	21892.734	47.428	.000 ^b
	Residual	14771.115	32	461.597		
	Total	80449.317	35			
^b Predictors: (Constant), Current, Flow Rate, Temperature						

In generalised form the prediction of the ultimate tensile strength for dissimilar weldment of ASME SA 213 Gr. T11 and BS 3059:1987 PT1 ERW 320 can be made from following equation:

$$UTS_{\text{dissimilar pre}} = 299.552 + (0.847 \times \text{Current}) + (2.747 \times \text{Flow Rate}) + (0.543 \times \text{Temperature})$$

CONCLUSIONS AND FUTURE SCOPE

The present study was aimed at investigating tensile strength of TIG welded joints of boiler steel tubes subjected to various ambient conditions for similar and dissimilar weldments. The outcomes of the current study have indicated the important influence of the variable process parameters in determining the tensile strength of the weldments, the results depicted are on the same track as discussed in literature [24] and [25]. The following conclusions have been drawn from the current study:

- Similar weldment of ASME SA 213 Gr. T11 material yielded maximum Ultimate Tensile Strength of 601.63MPa, when welded at 110A, under the inert gas flow of 10 Litre/min without any preheating.
- BS 3059:1987 PT1 ERW 320 has shown maximum tensile strength of 544.17MPa at 110A current and 10Litre/min flow rate of inert gas, when preheated at 150° C before welding.

- Dissimilar weldment has responded with maximum tensile strength of 563.49MPa, when preheated at 200° and welded at 110A current and flow of gas as 12 Litre/min.
- BS 3059:1987 PT1 ERW 320 yielded improved tensile strength in dissimilar weldment than that its parent strength, when it was pre heated at 200°.
- Multiple regression predicted maximum ultimate tensile strength significantly from the variable i. e. current, flow rate and temperature. All the three variables statistically significantly added to the prediction as per the equation $UTS_{T11\ pre}=316.18+(1.381 \times \text{Current})+(5.6 \times \text{Flow Rate})+(0.51 \times \text{Temperature})$ for ASME SA 213 Gr. T11.
- Statistically significant contribution of the said variables was explained by multiple regression for the prediction of UTS for BS 3059:1987 PT1 ERW320 as per the equation $UTS_{3059\ pre}=277.538+(1.287 \times \text{Current})+(6.374 \times \text{Flow Rate}) - (0.147 \times \text{Temperature})$
- Likewise the multiple regression for dissimilar weldment proved statistically significant effect of the process parameters on output as per the equation $UTS\ dissimilar\ pre=299.552+ (0.847 \times \text{Current})+(2.747 \times \text{Flow Rate}) + (0.543 \times \text{Temperature})$

No effort can be claimed to be perfect in all respects when it is the question of research work, there is always scope for future researchers to carry forward the research. Certain constraints have led to some limitations in present study which are surely scope for future work to be continued. Following are the said aspects:

- Other mechanical properties such as Torsion strength, fatigue strength and microstructural investigations can be carried out.
- More Process parameters can be included in the study.

ACKNOWLEDGMENT

The author is highly grateful to IK Gujral Punjab Technical University, Kpaurthala (Punjab), India, for the professional support from my supervisors Dr. Vikas Chawla and Dr. Gurbhinder Singh Brar.

REFERENCES

1. Lah, N. A. C., Ali, A. and Ismail, N. (2009), "Characterization of Fusion Welded Joint: A Review," *Pertanika J. Sci. & Technol.*, 17(2), pp. 201-212.
2. Shaikh, I. A. and Rao, M. V. (2015), "A Review on Optimizing Process Parameters for TIG Welding using Taguchi Method & Grey Relational Analysis," *International Journal of Science and Research*, 4 (6), pp. 2449-2452.
3. Vyas, A. H. and Patel, R. M. (2017), "A Review Paper on TIG Welding Process Parameters," *International Journal of Scientific Research & Development*, 5(2), pp. 1301-1304.
4. Anand, K. R. and Mittal, V. (2018), "Review On The Parametric Optimizat on Of Tig Welding," *International Research Journal of Engineering and Technology*, 4(1), pp. 1266-1268.
5. Garg, H., Sehgal, K., Lamba, R. and Kajal, G. (2019), "A Systematic Review: Effect of TIG and A-TIG Welding on Austenitic Stainless Steel," *Advances in Industrial and Production Engineering*, In: Shanker K., Shankar R., Sindhwani R. (eds) *Advances in Industrial and Production Engineering. Lecture Notes in Mechanical Engineering*. Springer, Singapore, pp. 375-385.

6. <https://axenics.com/blog/exploring-advantages-disadvantages-tig-welding> visited on June 6, 2019 at 1446Hrs
7. Kutelu, B. J., Seidu, S. O., Eghabor, G. I. and Ibitoye, A. I. (2018), "Review of GTAW Welding Parameters," *Journal of Minerals and Materials Characterization and Engineering*, 6, pp. 541-554.
8. Sathish., R., Naveen, B. Nijanthan, P. Geethan, K. A. V. and Rao, V. S. (2012), "Weldability and Process Parameter Optimization of Dissimilar Pipe Joints using GTAW," *International Journal of Engineering Research and Application*, 2(3), pp.2525-2530.
9. Hussain, A. K., Parmesh, T., Javed, M. and Lateef, A. (2012), "Influence of Welding Speed on Tensile Strength of Welded Joint in TIG Welding Process," *International Journal of Applied Engineering Research*, pp.518-527.
10. Pasupathy, J. and Ravisankar, V. (2013), "Parametric Optimization of TIG Welding Parameters using Taguchi Method for Dissimilar Joint (Low Carbon Steel with AA1250)," *International Journal of Science & Engineering Research*, 4(11), pp. 25-28.
11. Kumar, R. and Bharathi, S. R. (2015), "A Review Study on A-TIG Welding of 316(L) Austenitic Stainless Steel," *International Journal of Emerging Trends in Science and Technology*, 2(3), pp. 2066-2072.
12. Vidyarthi, R. S., Dwivedi, D. K. and Muthukumaran, V. (2018), "Optimization of A-TIG process parameters using response surface methodology," *Materials and Manufacturing Processes*, 33(7), pp. 709-717.
13. Srinivasan, R., Satyanarayana, J. D. V., Ramamoorthi, V., Pichumani, S. and Srikar, B. K. (2018), "Influence of Flux Coating During Dissimilar Welding of Copper with Brass Using ATIG Welding Process," *proc. 3rd International Conference on Advances In Manufacturing Technology*, pp. 95-103.
14. Muralimohan, N., Palanisamy, T., & Vimaladevi, M. N. (2014). *Experimental study on removal efficiency of blended coagulants in textile wastewater treatment. IMPACT: International Journal of Research in Engineering & Technology*, 2(2), 15-20.
15. Sathiya, P. and Srirangan, A. K. (2016), "Multi-Response Optimization Of Process Parameters For Tig Welding Of Incoloy 800ht By Taguchi Grey Relational Analysis," *Engineering Science and Technology, an International Journal*, 19, pp. 811-817.
16. Yan, G., Tan, M. J., Crivo, A., Li, F., Kumar, S. and Chia, C. H. N., (2017), "Improving The Mechanical Properties of TIG welding Ti-6Al-4V by Post Weld Heat Treatment," *Procedia Engineering*, 207, pp. 633-638.
17. Cai, Z., Feng, Kai., Yang, S., Liu, X., and Li, Z. (2018), "Characterization on the Microstructure Evolution and Toughness of TIG Weld Metal of 25Cr2Ni2MoV Steel after Post Weld Heat Treatment," *Metals*, 160 (8), pp.1-11.
18. Shi, Y., Cui, S., Zhu, T., Gu, S. and Shen, X. (2018), "Microstructure and intergranular corrosion behavior of HAZ in DP-TIG welded DSS joints," *Journal of Materials Processing Tech.*, 256, pp. 254-261.
19. Mishra, A. and Nidigonda, G. (2018), "Comparative Mechanical and Microstructure Properties Analysis of Friction Stir Welded and TIG Welded AA6061-T6 Similar Joints," *Journal of Advanced Research in Manufacturing, Material Science & Metallurgical Engineering*, 5(1&2), pp.1-8.
20. Sudheesh, P. K., & Govindan, P. (2013). *Experimental investigations and optimization of jig grinding process. International Journal of Research in Engineering & Technology*, 1(3), 65-76.
21. Gao, X. L., Zhang, L. J., Liu, J. and Zhang, J. X., (2014), "Comparison of Tensile Damage Evolution in Ti₆Al₄V Joints Between Laser Beam Welding and Gas Tungsten Arc Welding," *Journal of Materials Engineering and Performance*, 23 (12), pp. 4316-4327.

22. Chen, X., Yu, W., Jia, W., Xue, F., Yu, M., Liu, H. and Fan, M., (2019), "Thermal aging effect on the tensile and fatigue properties of the narrow-gap TIG welded joints in offshore floating nuclear power plants," *International Journal of Fatigue*, 126, pp. 143-154.
23. Yagati, K. P., Shibin, A. V., Joseph, J., Ezhuparayil, P. S., Thampi, S. and Chako, T., (2018), "Effect of Process Parameters on TIG Weld-Brazing of Aluminum Alloy to Galvanized Steel," *Journal of Thin Films, Coating Science Technology and Application*, 5 (3).
24. Balaram, A., Naik, A. and Reddy, C. (2018), "Optimization of tensile strength in TIG welding using the Taguchi method and analysis of variance (ANOVA)," *Thermal Science and Engineering Progress*, 8, pp. 327-339.
25. Chaudhari, S. C., Yadav, C. O., & Damor, A. B. (2013). A comparative study of mix flow pump impeller cfd analysis and experimental data of submersible pump. *IJRET*) ISSN, 2321-8843.
26. Ahmad and Alam (2018), "Grey Based Taguchi Method for Optimization of TIG Process Parameter in Improving Tensile Strength of S30430 Stainless Steel," *IOP Conf. Ser.: Mater. Sci. Eng.* 404.
27. Chaudhary, V., Bodkhe, V., Deokate, S., Mali, B. and Mahale, R. (2019), "Parametric Optimization Of Tig Welding On Ss 304 And Ms Using Taguchi Approach, " *International Research Journal of Engineering and Technology*, 6(5), pp. 880-885.
28. Gopinath, V., Kumar, M. T., Sirajudeen, I., Yogeshwaran, S. and Chandran, V. (2015), "Optimization Of Process Parameters In Tig Welding Of Aisi 202 Stainless Steel Using Response Surface Methodology," *International Journal of Applied Engineering Research*, 10(13), pp. 11053-11055.

